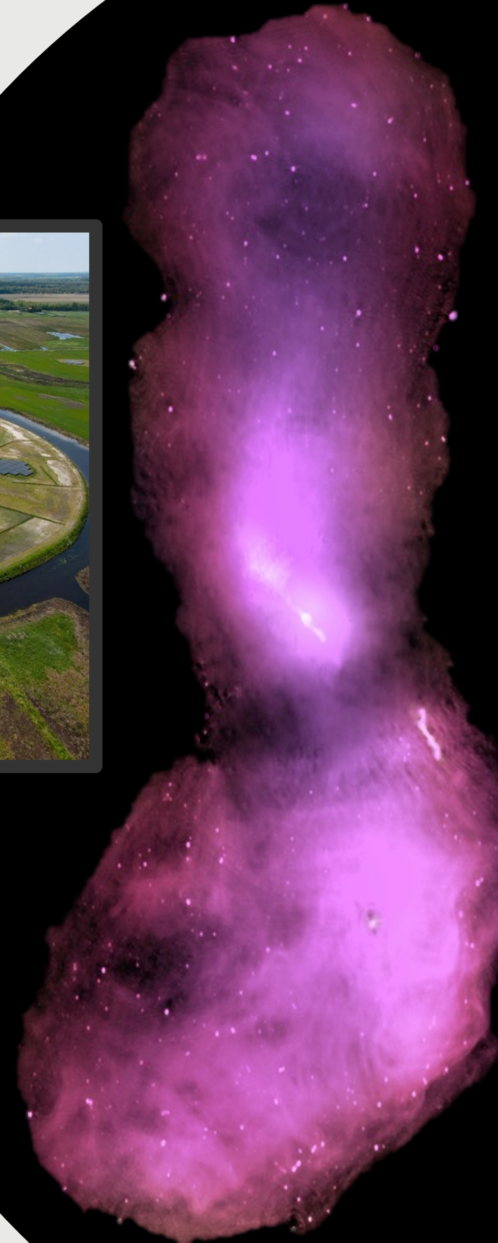
Fringe Fitting: Correcting for delays and rates in VLBI



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DEVELOPMENT IN AFRICA WITH RADIO ASTRONOMY

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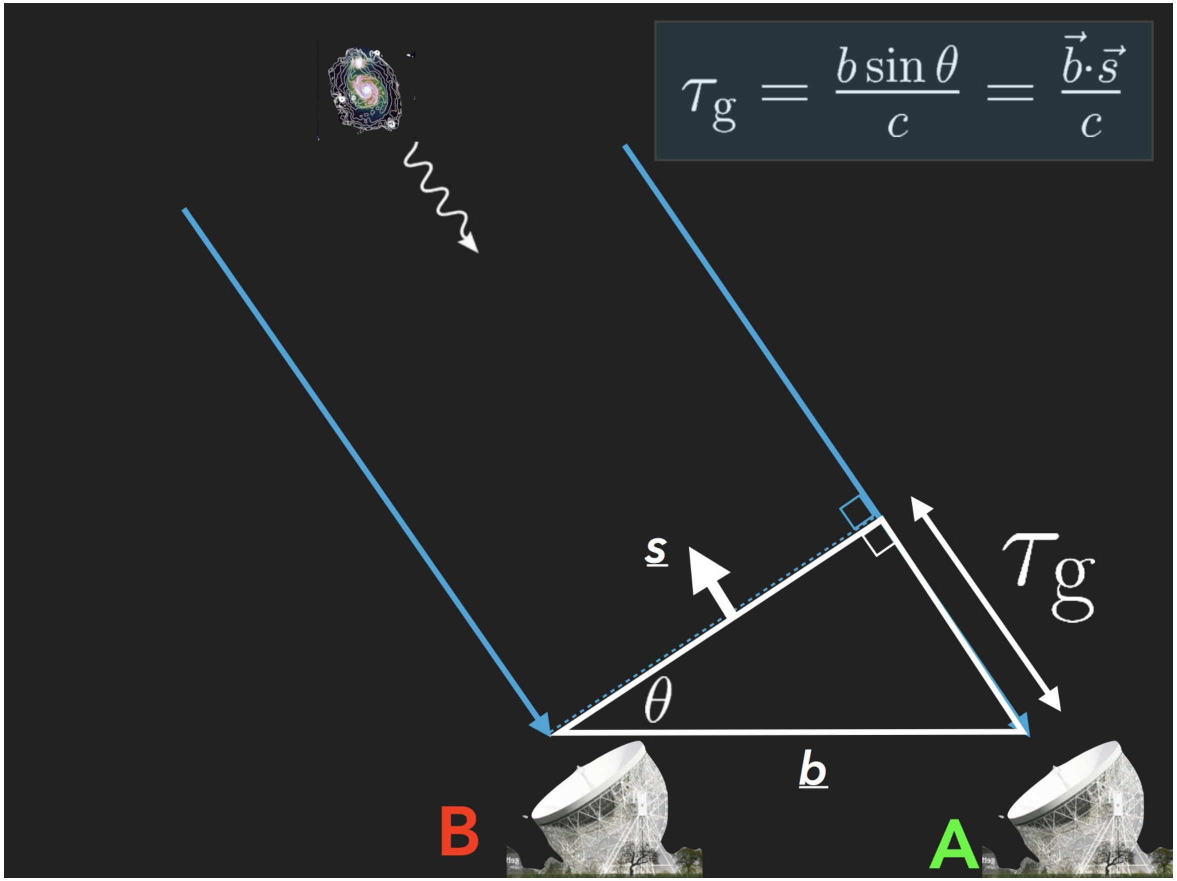
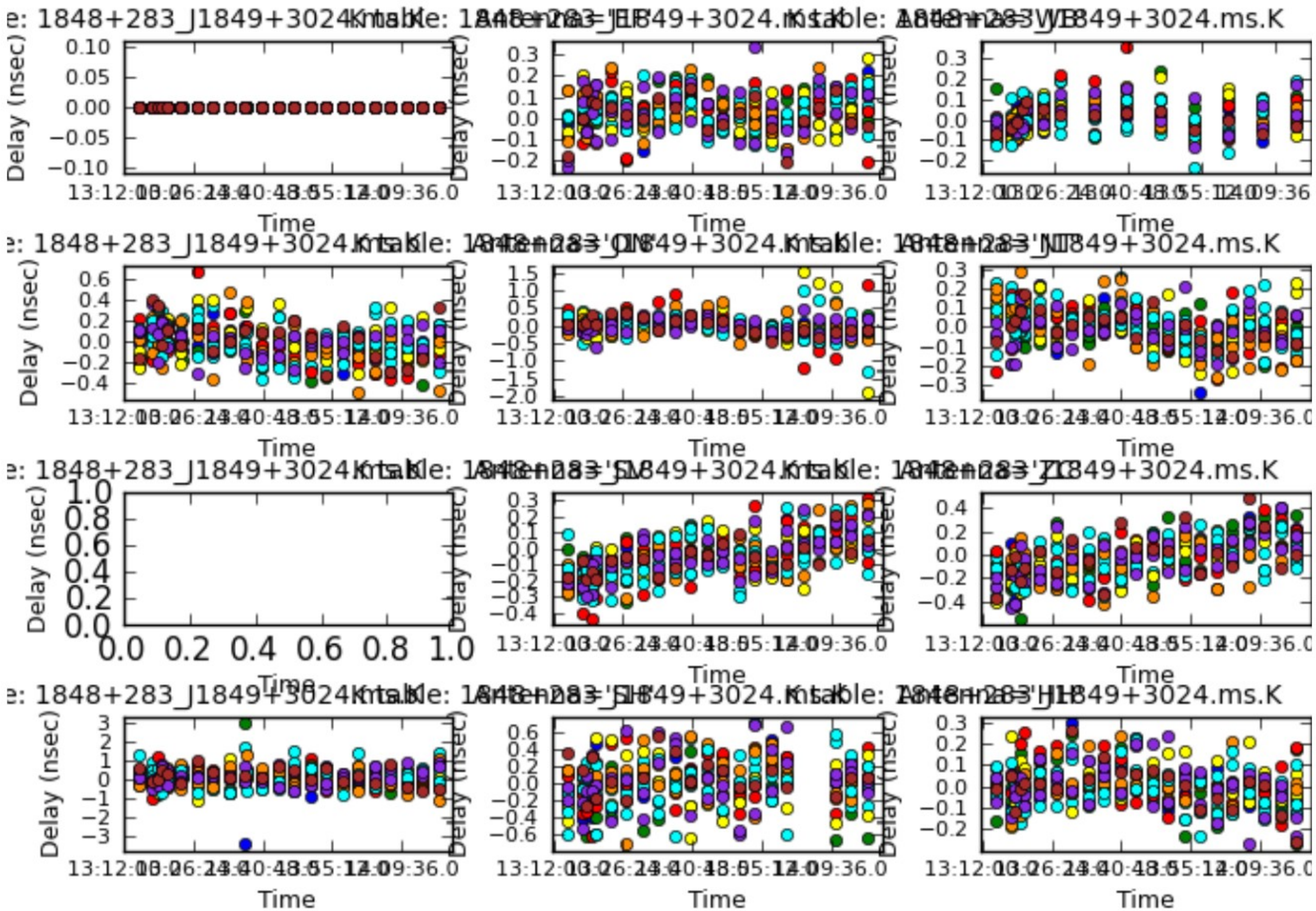
Intro to fringing

- As we know, signals detected by an interferometer are affected by a time delay (geometric time delay)
- Correlator corrects for the changes in delay but the model will have errors with get worse with distance. Correct using fringe-fitting – generalisation of phase self-cal. So fixing bad delay calibration



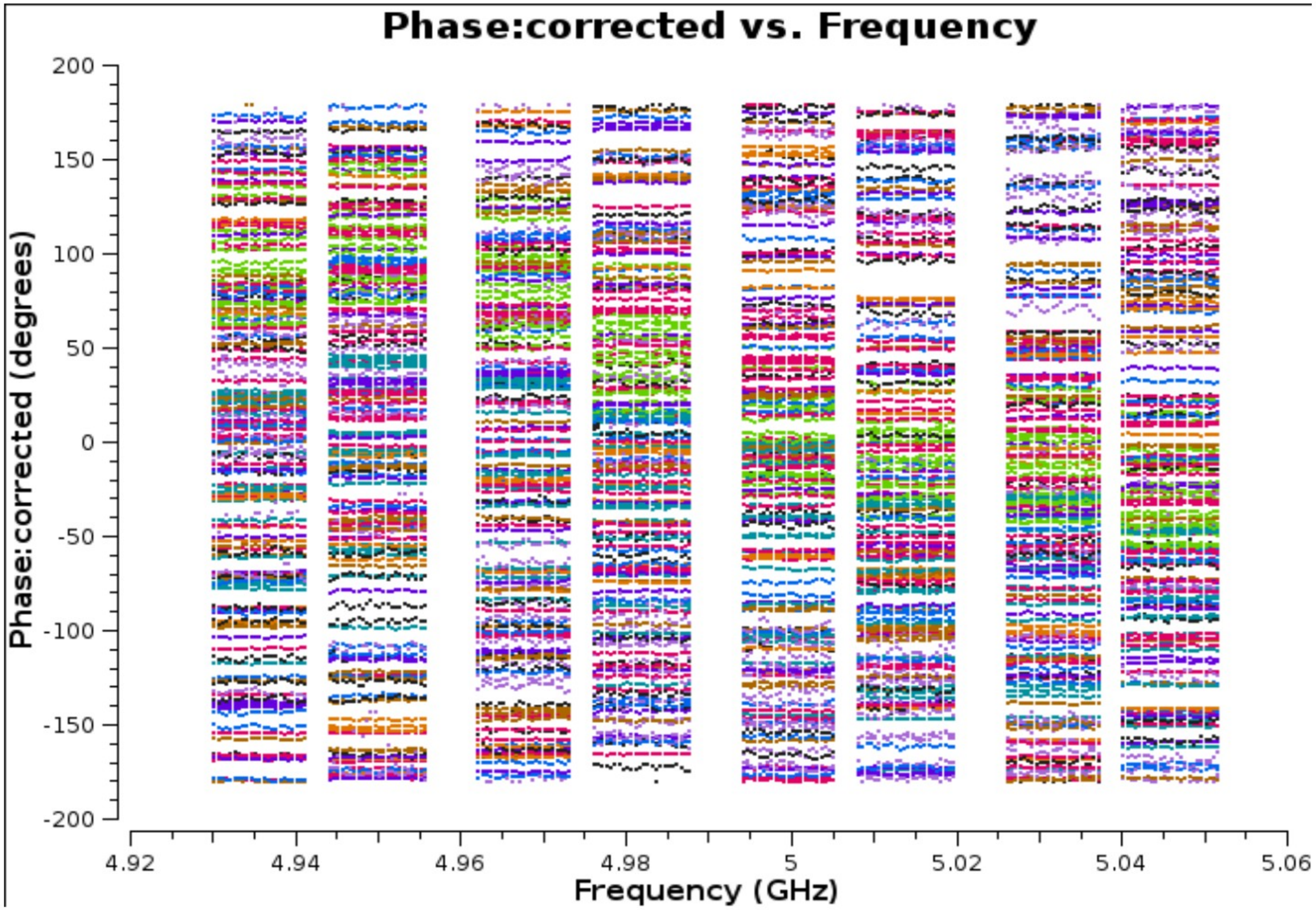
What the fring?

› So you have applied Tsys, delay, bandpass, phase, and amplitude corrections on your bright primary calibrator. Delays are close to zero, but with a signifcant variation. This is ok for bright sources:



What the fring?

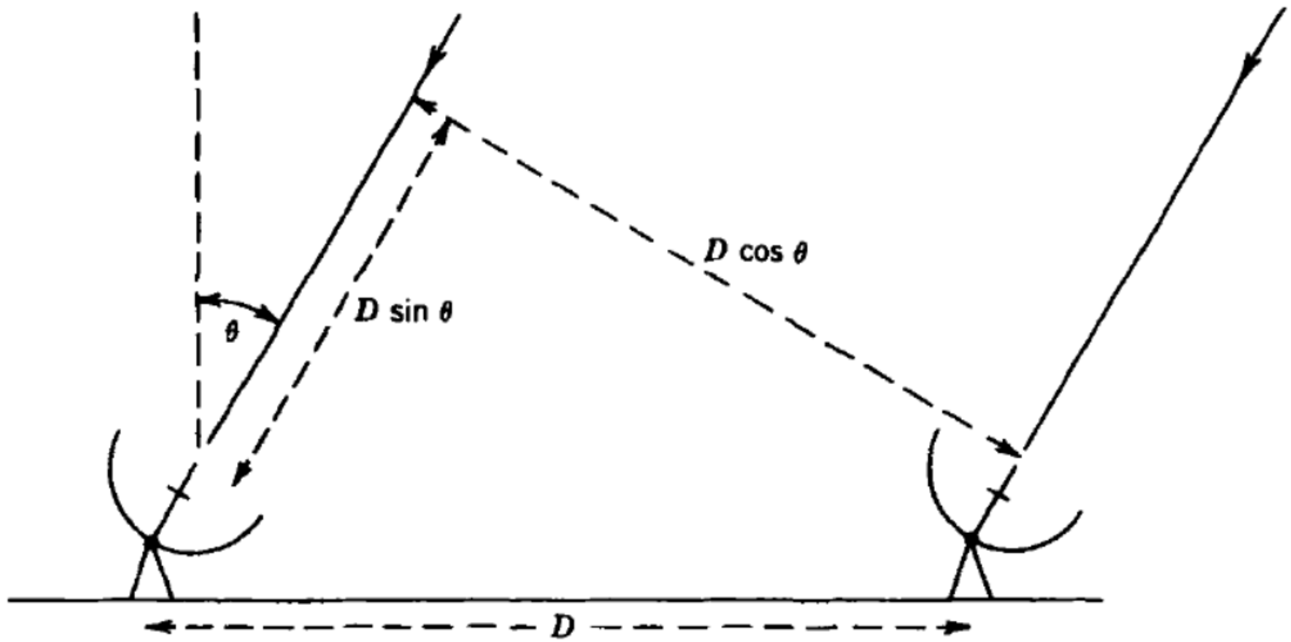
- Phases are constant but not at zero. This is not okay for faint sources



Why is this a worry now?

- Largely due to clock problems at the different locations - you have clock drift that is small but can amount to a problem.
- Other interferometers (ATCA, JVLA) have only one clock
- Also changes of baseline geometry due to tidal effects
- Some atmospheric affects

Fringing



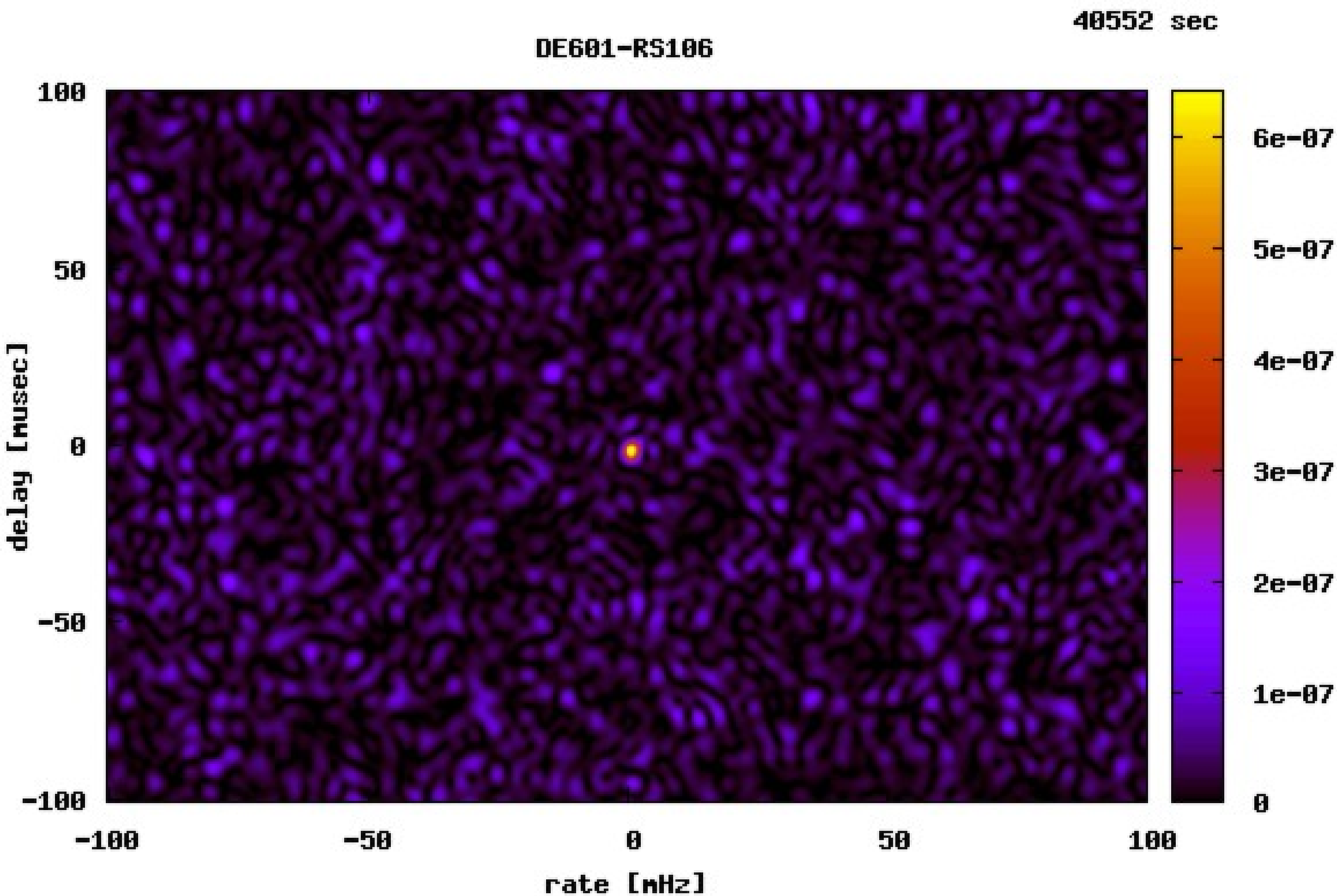
- Wavefronts of a signal from a distant source, arrives at one antenna with a geometrical delay, $\tau_{obs} = D/c \sin\theta$
- $\Phi = 2\pi\nu\tau_{obs}$ (interferometer phase)
- τ_{obs} changes with time → fringe rates

Linear approach

$$\phi(t,\nu) = \phi_0 + \frac{\partial\phi}{\partial\nu}\Delta\nu + \frac{\partial\phi}{\partial t}\Delta t \quad \text{[+dispersive delay]}$$

- have to determine
  - ⋆ phase ϕ_0
  - ⋆ delay $\frac{\partial\phi}{\partial\nu}$
  - ⋆ rate $\frac{\partial\phi}{\partial t}$
- delays and rates are stable over a longer time and wider band than $\phi(t,\nu)$
- the process to find phase, delay, rate is called 'fringe-fitting'

Delay versus rate



Solving for delay versus rates

- Sources of delay and rate errors can be separated into contributions from each antenna
- Baseline dependent errors → difference of antenna dependent errors
- Phase errors for baseline i,j

$$\Delta\phi_{ij} = \phi_{i0} - \phi_{j0} + \left(\left[\frac{\partial\phi_i}{\partial\nu} - \frac{\partial\phi_j}{\partial\nu}\right]\Delta\nu + \left[\frac{\partial\phi_i}{\partial t} - \frac{\partial\phi_j}{\partial t}\right]\Delta t\right).$$

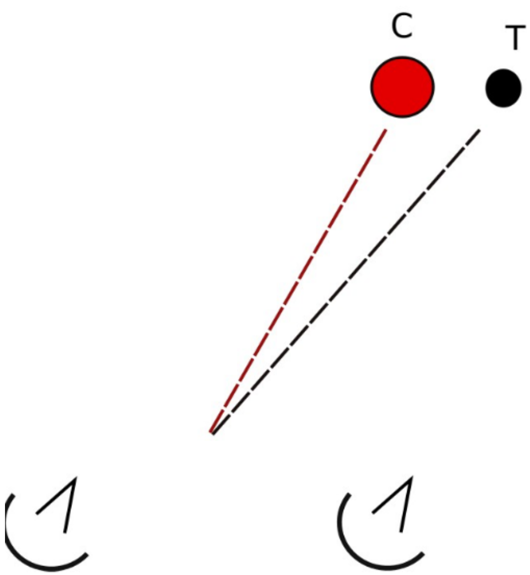
- Fringe-fitting involves solving the above equation, to obtain the errors via observations of a bright calibrator
- Without doing this you can not average in phase and time (really bad for weak targets)

AIPS – Global fringe fitting

- Use all baselines to jointly estimate the antenna phase, delay and rate relative to a reference antenna
- Solves the baseline phase error equation, with one of the antennas set to the reference antenna
- Delay, rate and phase residuals for reference antenna are set to zero
- Hence only measures difference, not absolute errors
- Assumes calibrator is a bright point source at phase center
- Similar to self-calibration as source structure is part of the model
- Implemented in AIPS (ancient radio astronomy package) but soon to be implemented in CASA (v5.3.3 and greater)

Phase Referencing

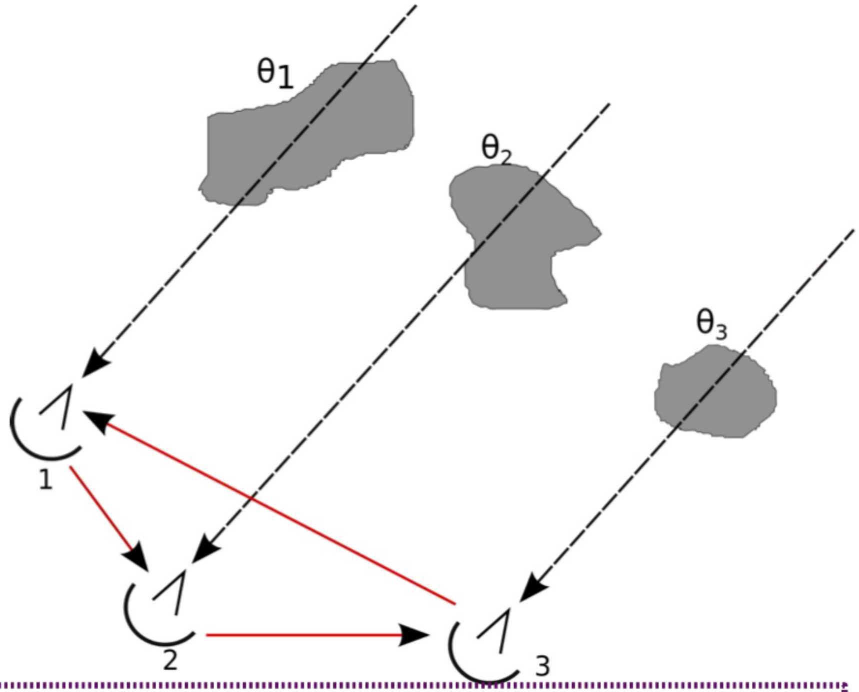
› Similar to what we have seen for our secondary calibrator, just need to be closer



- Fringe-fitting requires observations of a bright, compact source → the phase-calibrator, C.
- Nodding between C and target (T)
- Cycle time must be shorter than the atmospheric fluctuations
  ~10 mins at 5 GHz; ~5 mins at 1.6 GHz
- C must be close to T (< 1 deg)
- Antenna positions must be known to within a few cm!
- Obtain solutions of the phase, rate and delay by applying the Fringe-fitting technique to C and interpolate to T

Issues:
- wet troposhere & fewer calibrators at high freq
- Ionosphere at low freq

Closure Phases



Original ref: Rogers et al 1974, ApJ, 193, 293

Phase contributions from each baseline =
true phase + (difference between the random atm phases)

12-> $\Phi_{12}=\phi_{12}+\theta_1-\theta_2$

23-> $\Phi_{23}=\phi_{23}+\theta_2-\theta_3$

31-> $\Phi_{31}=\phi_{31}+\theta_3-\theta_1$

Summing the total phases from each baseline, the phases from the atm cancels:

$$\phi_c=\Phi_{12}+\Phi_{23}\Phi_{31}+noise$$

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- All antennas have different random phase fluctuations -> atmosphere
- Closure phase, φ_c = sum of simultaneously observed phases of a source on 3 baselines forming a triangle

$$\varphi_c = \varphi_{12} + \varphi_{23} + \varphi_{31} + \text{noise}$$

- Indep. of station based phase errors
- Phase errors due to atmospheric variations are cancelled
- Fringe-fitting (and self-cal) uses this triangle to solve for the residual phases, rates and delay

Conclusions and tips

- VLBI observations, due to an imperfect delay model, will introduce residual phase, delay and rate errors
- These errors change with time and frequency, so must be removed before imaging to avoid decorrelation
- This is only a concern (largely) of VLBI observations of faint targets